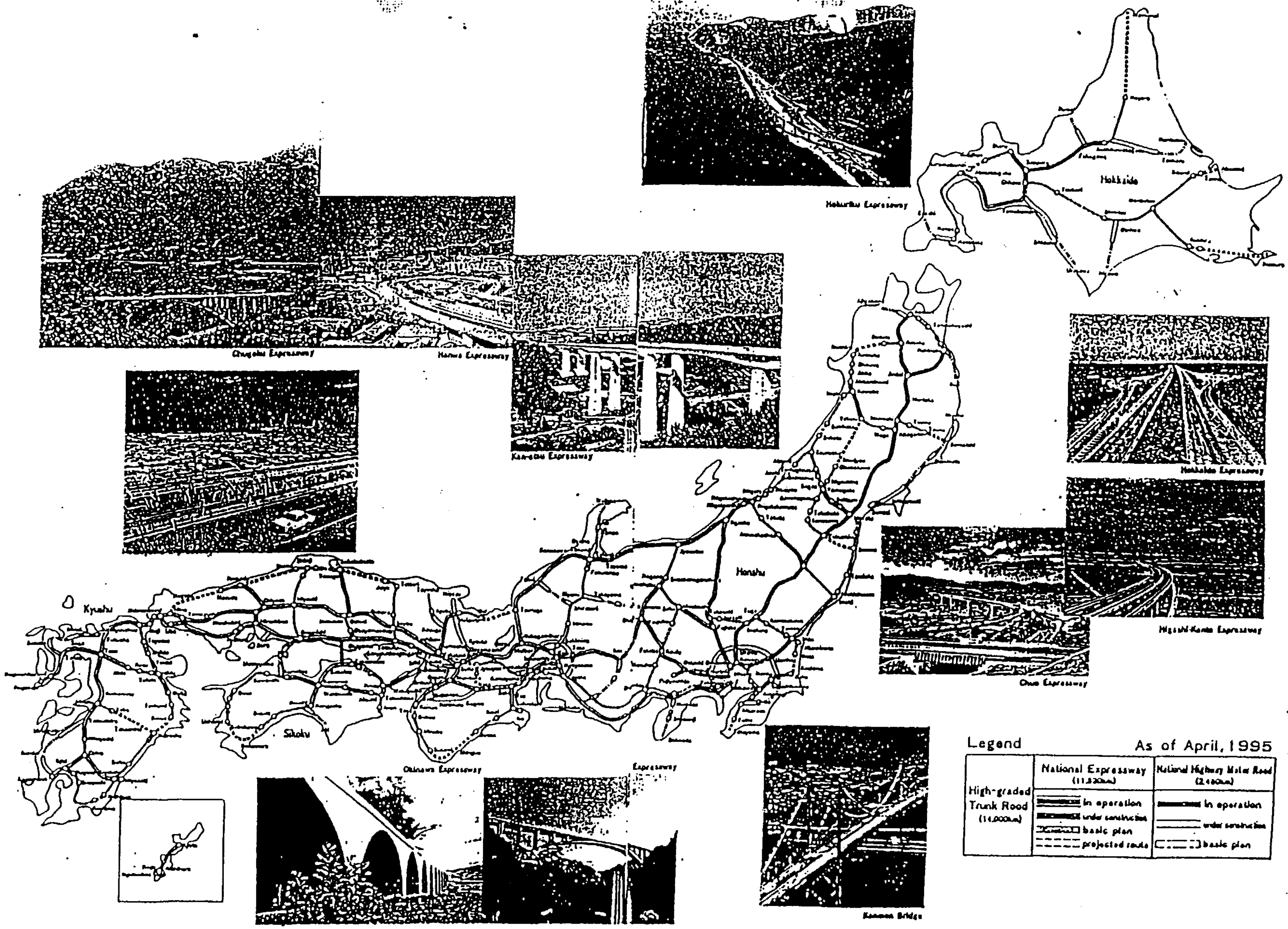

Fig. A1 Road Networks

Attachment 5 to Appendix L

ARINC, Dedicated Short Range Communications (DSRC) 5.8 GHz Band Occupation Considerations

DEDICATED SHORT RANGE COMMUNICATIONS (DSRC) 5.8 GHz BAND OCCUPATION CONSIDERATIONS

Introduction

This paper provides additional information to be used as rationale for requesting the FCC to allocate the entire 5.850 to 5.925 GHz band for DSRC communications.

The Japanese DSRC standards working group, ISO/TC204/WG15 Committee of Japan, has recently provided the U.S. DSRC standards working group, ASTM E17.51, with several documents describing the draft Japanese DSRC standard. This draft standard is the result of at least 29 million dollars of research since June 1995. During this time many different systems were tested including CEN pre-standard backscatter systems, a 5.8 GHz active system derived from the Hughes specification, and an Amtech 5.8 GHz backscatter system, among others.

The Japanese draft standard combines many of the characteristics of those tested into one system and adds some improvements. This is very similar to the approach that the ASTM writing groups are taking with the 902 to 928 MHz draft standard and would probably take with the 5.850 to 5.925 GHz draft standard. It is expected that the ASTM writing groups will consider the characteristics of the Japanese and CEN draft standards very seriously in their development of a U.S. standard.

New Information

The Japanese draft standard specifies carrier frequencies to be selected by country in the 5.8 GHz ISM band and specifies two downlink channels 10 MHz apart. The uplink channels are also specified as two channels 10 MHz apart. In addition it specifies that each downlink and uplink carrier frequency pair be separated by 40 MHz. Each channel is required in the spectrum mask sections to have an occupied bandwidth of ≤ 8 MHz. The 10 MHz separation allows a 2 MHz guard band. Therefore, each channel is essentially 10 MHz wide. This means 20 MHz of downlink channels, 20 MHz of separation, and 20 MHz of uplink channels. This standard is an active transponder approach with a maximum beacon power of + 46 dBm and an transponder power of + 10 dBm or more. The range for beacons with + 46 dBm EIRP, is expected to be about 50 meters and the reuse distance for beacons with + 16 dBm EIRP, is about 9 meters.

Relevance

If the U.S were to adopt the Japanese draft standard adjusted to the 5.850 to 5.925 GHz band or use most or all of its characteristics in the U.S. ASTM DSRC standard we would need all 75 MHz, allowing for a 2.5 MHz guard band on each end, to implement this approach.

In a dual mode environment where both backscatter and active equipment would be operating in the band, the backscatter equipment could operate in the separation space between the active bands. Also, the backscatter equipment could operate in the active equipment channels if active equipment were not present in particular locations.

In addition, where the noise from military or satellite uplinks could interfere with the active system a dual mode system could switch to backscatter and move the operating frequency away from the interference.

SPECTRUM REQUIREMENTS FOR DEDICATED SHORT RANGE COMMUNICATIONS (DSRC)
Public Safety and Commercial Applications

July 1996

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AEI - Automatic Equipment Identification
AGC - Automatic Gain Control
AHS - Automated Highway System
ASK - Amplitude Shift Keyed
CRC - Cyclic Redundancy Check
CVO - Commercial Vehicle Operations
CW - Continuous wave
DSRC - Dedicated Short Range Communications
EIRP - Effective Isotropic Radiated Power
ELP - Electronic License Plate
ETC - Electronic toll collection
ETTM - Electronic Toll & Traffic Management
FCC - Federal Communications Commission
FHWA - Federal Highway Administration
GaAs - Gallium arsenide
HAR - Highway Advisory Radio
IR - Infrared
ISM - Industrial, Scientific and Medical
ISP - Information service provider
ITS - Intelligent Transportation System
LMS - Location and Monitoring Service
NTIA - National Telecommunications and Information Administration
OOK - On/Off Keying
RF - Radio frequency
RFID - Radio Frequency Identification
RTTT - Road Traffic and Transport Telematics
TDMA - Time division multiple access
TIRS - Transportation Infrastructure Radio Services
TMC - Traffic Management Centers
WIM - Weigh in motion

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SPECTRUM REQUIREMENTS FOR
DEDICATED SHORT RANGE COMMUNICATIONS (DSRC)
Public Safety and Commercial Applications

1.0 INTRODUCTION

This is the third in a sequence of papers that present the factors involved in identifying the radio frequency spectrum required for both current and future DSRC operations. Since the proposed applications, signal characteristics and channel allocation have been evolving over the course of the spectrum requirement analysis these papers have represented the information available at the time of printing. The first paper was titled "Spectrum Requirements for Vehicle To Roadside Communications (VRC)," dated October 1995, and discussed the basic requirement to have a sufficient number of channels and spectrum available to accommodate all the potential applications of this communications method. The second paper was titled, "Updated Spectrum Requirements for Dedicated Short Range Communications formerly Vehicle To Roadside Communications (VRC)," dated March 1996, and added more detail on the interference potential between applications and an environmental perspective. This current paper presents more information on applications, additional considerations in channel assignments, a change in potential signal characteristics, more information on channel bandwidth calculations and information on channel reuse distances. The development of the expectations for this communications area has matured sufficiently that this paper presents a firm estimate for DSRC spectrum requirements.

1.1 Intelligent Transportation Systems

The Intelligent Transportation Systems (ITS) will reflect the result of using advanced and emerging technologies in such fields as information processing, communications, control, and electronics on our U.S. intermodal transportation infrastructure to improve the safety and increase the efficiency of the current transportation system. The goals of ITS are to reduce energy use, increase economic productivity, increase public mobility, and encourage the application of new technologies to initiate new industries. [1]

1.2 Dedicated Short Range Communications

1.2.1 Purpose and Description

1.2.1.1 Purpose

A critical component of the ITS is dedicated short range communications (DSRC) and the applications that use this communications method. Each DSRC application, when used, occupies some specific bandwidth within the electromagnetic spectrum. This paper presents a discussion of the radio frequency (RF) bandwidth required for implementation of all of the currently proposed DSRC applications. It also explains how that bandwidth relates to a request for allocation of a portion of the managed RF spectrum.

1.2.1.2 DSRC Description

DSRC consists of short-range communications devices that are capable of transferring high rates of data over an air interface between mobile or stationary vehicles and normally stationary devices that are mounted to structures along the roadway or are hand-held [2,3]. There are several methods that are currently being used to accomplish this communication including optical beacons, spread spectrum radio, infrared (IR) beacons, and RF beacons. The paragraphs that follow describe typical current applications of these technologies; they do not necessarily present the maximum capability of each technology, for example in other than highway applications.

1.2.2 Optical Beacon Description

Optical beacon technology is currently being used only for traffic signal preemption and priority. Optical beacon technology consists of three basic elements: an optical emitter, an optical detector, and a phase selector that is usually connected to a traffic signal controller. The optical emitter produces high intensity encoded optical pulses and is mounted on an emergency vehicle. The optical detector receives the pulses and sends the corresponding electrical signals to the phase selector. The phase detector discriminates between valid emitter signals and other sources of optical energy and sends signals to the traffic signal controller to activate the desired green signal for the emergency vehicle. The optical beacon is capable of communicating the vehicle presence, category, three digit ID number and an activation range setting.

Optical signal preemption and priority systems are currently being used for emergency vehicles in some locations where fog and dense rain are unusual occurrences, line-of-sight is not a problem, but technician RF licensing is a concern. A high data rate is not required in these applications and they are used where a range of up to 2500 feet is desired. The qualifications for application of an optical preemption system are listed below:

- The vehicles are used to respond to emergency situations or operate in the mass transit system;
- The number of vehicles is small;
- The vehicles are not expected to leave the area to use other DSRC systems; and
- The environmental conditions are favorable.

For those applications that are peculiar to emergency and transit vehicles and meet the above listed conditions the optical systems have been installed as acceptable priority control equipment. However, it is not designed to transmit a high data rates and only transmits one way, so it is not a system that can implement two way high data rate applications.

1.2.3 Spread Spectrum Radio Description

Spread spectrum technology is currently being used for traffic signal preemption and priority. It consists of two groups of elements: a transmitter, compass, and vehicle antenna; and a detector antenna and receiver module. The transmitter and compass are mounted in the emergency vehicle. The compass provides directional information to be transmitted to the traffic controller. The vehicle antenna is mounted on the roof of the emergency vehicle. The detector antenna is mounted on the traffic signal support device, receives RF signals, and sends them to the receiver module. The receiver module is connected to the traffic signal controller. It decodes the signal and sends requests to the traffic signal controller to activate the desired green signal for the emergency vehicle. Data rates of up to 256 Kbits/sec can be achieved in the 902 to 928 MHz band and ranges of 3000 feet and greater are typical.

Spread spectrum radio signal preemption and priority systems are currently being used for emergency vehicles in some locations where all weather operation is desired; line-of-sight could be a problem, but technician RF licensing is not a concern. A high data rate is not required in this application, and it is used where a range of 3000 feet or more is desired. Although a high data rate is not required in the signal preemption application, some equipment types are capable of transmitting up to 256 Kbits/sec in the 902 to 928 MHz band and more at higher frequencies; however, for high data transmission rates, expensive transceivers are required on both sides of the link. Therefore, since it may be too expensive for some other applications, it would probably not be economical to use this technology for all applications.

1.2.4 IR Beacon Description

Typical IR beacon technology consists of three basic elements: an infrared transceiver, beacon head, and a beacon controller. The IR transceiver, which is part of the in-vehicle unit, receives data from the beacon head in the down link signal, and replies with its own encoded IR uplink signal. It is usually mounted in the vehicle behind the windshield. The beacon head is usually mounted on the traffic signal support pole, mast or wire. Its function is to transmit the encoded IR signal to the in-vehicle unit and receive the uplink from the in-vehicle unit. The beacon controller is connected to the beacon head by a wire link through which it establishes the timing and protocol of the data output, sends the data to be transmitted, and collects the information received from the in-vehicle unit. The beacon controller is also connected to the application computer from which it collects data to be sent, and to which it sends the data collected. The data rates are 500 Kbits/sec downlink and 125 Kbits/sec uplink. The range is about 197 to 262 feet (60 to 80 meters).

Infrared beacons have been used to demonstrate toll collection capability, are being used for traffic information and route guidance, and could be used for transit vehicle data upload. IR systems are being used in Europe, Japan and in a demonstration system in the United States for traveler information systems and route guidance. However, the IR beacon is not currently being widely deployed in the United States. If the IR beacon were used as an alternative DSRC system in places where nationwide interoperability would not be required, it could be used for a community specific local traffic information and route guidance system. It could also be used in those applications, such as transit vehicle data upload, where the vehicle type is specifically designed for the application, the number of vehicles is relatively small, and the vehicles are not expected to leave the area to use other DSRC systems.

1.2.5 Safety Warning System™ and the Safety Alert™ Traffic Warning System

The Safety Warning System™ and the Safety Alert™ Traffic Warning System are being developed to provide advance warning of hazards on the roadway. These warning systems consist of a small radar frequency transmitter and a radar detector. The radar detector is similar to the familiar equipment used to detect police radar activations. The radar frequency transmitter would be attached to hazard signs or other equipment and broadcast a code on a 24 GHz carrier that the radar detector could use to either activate on, or decode and display a message. The radar transmitter is expected to be an inexpensive device compared to an RF beacon, but the radar detector would cost more than the ordinary RF tag.

This system is a one-way communication device that sends warnings of railroad crossings, school zones, fog, and other hazards to vehicles with radar detectors. It serves the function of providing position-related hazard information. It can not be used for applications requiring two-way communication.

These systems are a positive first step in the direction of enhancing the traffic warning capability by using electronics. However, these systems currently have a limitation that is applicable to nationwide deployment. Radar detectors are not allowed by law in several states. This will, unless the laws are changed, limit the deployment of these devices.

1.2.6 RF Beacon Description

RF beacon technology consists of three basic elements: a transponder (tag), transceiver (reader), and transceiver antenna (beacon). But this delineation is not always clearly observable as some configurations combine the transceiver and the antenna into one unit and call it a beacon. The tag is also capable of being divided into an antenna and an electronics package. The tag is a processor-controlled data transfer device (read only) or low-power transceiver (read-write) that stores data. Some tags are designed to be mounted on the inside of the vehicle (i.e., windshield or dash), some are designed to be mounted on the outside of the vehicle (i.e., trailer door), and others may have the antenna located outside of the vehicle (i.e., on the windshield, license plate, or bumper), with the electronics mounted inside the vehicle body. The tag responds to communications sessions initiated by the reader.

The reader is a transceiver with a more powerful processor and transmitter than the tag. The reader controls all communications sessions and is usually installed in a cabinet alongside the roadway with the antenna mounted on a structure overlooking the roadway. Reader antennas can also be incorporated into existing traffic signs to minimize the need for additional roadside structures (improve safety) and to camouflage the antennas (minimize vandalism). In addition, readers are made in portable and handheld versions. Portable readers would be used in applications such as portable signs and handheld readers could be used by vehicle inspection personnel.

Two basic designs of RF tags—active and backscatter—are currently in use. The active design transmits a return signal, while the backscatter type reflects and modulates the reader signal. Active tags have a longer range than the backscatter designs given the same reader antenna output power. However, the active tag would need a complicated transmitter to transmit at different frequencies. Therefore, it would need to be larger, cost more and use more power than similarly capable backscatter tags. The backscatter tag has the ability to respond to different frequencies that the reader may use without requiring more circuitry and packaging space. In addition, backscatter tags usually cost less than active tags. Backscatter tags are available in two types: semi-active and passive. The semi-active tag contains a battery or can be connected to the vehicle power supply to provide operational power for the processor, memory and modulation circuits. But it does not use power to transmit RF energy, it only reflects the beacon's signal. The passive tag receives all of its power from the beacon signal. The specifications for several RF Beacon systems are listed in Appendix A.

The capabilities of the tags are indicated by four types, as listed below:

- Type I - read-only, limited permanent storage (128 - 256 bits), and usually passive backscatter design;
- Type II - read/write, substantial programmable memory (512 bits - 16 Mbits), and active or semi-active design;
- Type III - read/write, substantial programmable memory (512 bits - 16 Mbits), active or semi-active design, user interface (lights, sound, display), and an interface to an on-board computer or smart card reader; and
- Type IV - read/write, substantial programmable memory (512 bits - 16 Mbits), active or semi-active, user interface (lights, sound, display), integral smart card reader, and an interface to an on-board computer.

Currently, both active and backscatter RF tag types are used to implement the different DSRC applications. For example, in open road information transfer, where two or more vehicles are communicating and a substantial line-of-sight distance is desired, the active type would require less reader output power and would be less subject to interference. The interference improvement results from the higher signal output of the active tag. This allows the reader receiver sensitivity to be much less than the backscatter tag and therefore less susceptible to other signals.

However, where precise location is required with only one vehicle at a time, the backscatter system would require less power from the tag, cost less, and be more compatible with small separation distances between applications. The backscatter system can also perform open road information transfers at distances approaching 100 feet. Therefore, both the Federal Highway Administration (FHWA) ITS Architecture Team and the Intelligent Transportation Society of America CVO (Commercial Vehicle Operations) Technical Committee support the use of both types of tags. However, a primary incentive to rapid DSRC implementation is the development of national DSRC interoperability that is most cost-effective for the public. As more experience is gained with DSRC applications, a single tag type that supports the interoperability requirement, in a cost-effective way, is expected to emerge.

1.2.7 Communications Technology Focus

Optical beacons, IR beacons, spread spectrum radio, the Safety Warning System™, the Safety Alert™ Traffic Warning System, and RF beacons each have characteristic advantages and disadvantages that encourage their use in particular circumstances. However, customer utilization, and economic, management, and manufacturing efficiencies can be gained from developing a standard system for common applications. The applications where standardization is of most concern involve the private vehicle system and the commercial vehicle system. Representatives from some vehicle manufacturers have said that the in-vehicle DSRC component will have a very low chance of being installed in production vehicles by the manufacturer until the communications interface is standardized. The method gaining most acceptance in DSRC for implementing common high data rate ITS applications is the RF beacon.

The RF beacon has several advantages. It can:

- provide two-way communications;
- provide a high data rate that is sufficient for all applications;
- focus on a very small communication zone or communicate with every vehicle on the roadway; and
- operate in all weather conditions.

The in-vehicle unit can be made inexpensively, and comparable systems are available from several manufactures. Therefore, since the RF beacon technology is being used in all the current types of applications and can be used in all of the proposed ITS applications, the following sections of this paper will discuss the considerations for implementing RF beacon technology.

1.3 Bandwidth Requirement Development

The following sections of this paper explain the characteristics of the recommended RF DSRC communication implementation and develop the requirements for the bandwidth to support it. Section Two explains the nature and purpose of the applications being supported. Section Three discusses how the applications use DSRC communications and explains the need for a number of communications channels. Section Three continues by working out a rationale for channel assignment and explains how it is implemented to accomplish the communications requirements. Section Four explains the method used to develop a data rate from the amount of data to be transmitted and the circumstances of the transmission. Section Four also shows the result of the data rate computations, develops a channel data rate, and determines the bandwidth needed to support the DSRC communication requirements. Finally, Section Five explains the current DSRC uses of the RF spectrum, and details the rationale for suggesting a particular spectral location for the required bandwidth.

2.0 DSRC APPLICATIONS

The following ITS applications are being implemented or are being considered for implementation with DSRC [2,3]:

- In-vehicle signing;
- International border clearance;
- Electronic clearance;
- Safety inspection;
- Fleet management;
- AEI and Freight management;
- Off-Line verification;
- Electronic License Plate (ELP);
- Traffic network performance monitoring;
- Intersection collision avoidance;
- Emergency vehicle signal preemption;
- Transit vehicle signal priority;
- Transit vehicle data transfer;
- Traffic information dissemination;
- Automated highway system-to-vehicle communications;
- Electronic toll collection (ETC);
- Parking payments / Access control; and
- Drive-thru payments

Those applications that are implemented or sponsored by government (public) agencies are considered public safety applications and those implemented by private business concerns are considered commercial. Many of the applications, including electronic clearance, intermodal freight management, ETC, and traffic network performance monitoring are already being implemented. Commercial vehicle operations (CVO) applications include several of those listed above and are expected to be some of the first seeing wide implementation. Implementation characteristics for the remaining applications are currently being developed. Hazardous material incident response has been removed from the list since it will be accomplished through wide area communications. However, because a scenario of operation is necessary to compute bandwidth requirements, the preliminary operational characteristics described in the following sections are assumed for the applications being evaluated.

2.1 In-Vehicle Signing

In-vehicle signing refers to the display (and annunciation, where necessary) of available roadside sign information inside the vehicle. In-vehicle signing may be used to enhance the effectiveness of information available from the roadside and provides the driver with a more effective way to receive sign information when driving in poor weather conditions or over difficult terrain. If a DSRC-equipped road sign is obscured by snow or a dust storm, the driver sees the information that the sign was installed to present on a display inside the vehicle. This information can include advisory, regulatory, and warning signs.

The currently proposed method of implementing sign-to-vehicle communications is beacon technology, which is especially applicable for regulatory and warning signs. Beacon technology allows the driver to receive notification of an important, critical, or dangerous road situation, specific to a location, only when that situation is present in the roadway. Data about ice on the roadway or speed limit changes because of road construction are primary candidates for beacon communications. Beacon technology usually transfers information in milliseconds which, in combination with the consideration of vehicle speed, makes beacons preferable for use in position-, condition-, and time-critical communications applications. Beacons also have the advantage of transferring information in all light and weather conditions. In addition, in-vehicle signing equipment can display the information in the vehicle for a much longer period than non-instrumented signs, especially in poor visibility conditions.

In-vehicle signing can be compared with a safety feature such as anti-lock brakes. Just as anti-lock brakes improve the wet-road performance of a normally adequate brake system, in-vehicle signing improves the performance of road signs where hills, foliage, snow, fog, rain, dust, or lack of nighttime illumination present visibility problems.

An alternative source for sign information is in-vehicle navigation systems, which are updated through wide-area communications equipment and are suitable to support advisory and static regulatory signs. The navigation system signs would be documented and updated by the information service provider (ISP) supporting the navigation system.

2.2 International Border Clearance

All vehicles are required to stop at international border checkpoints where they undergo inspections for clearance to pass across the border. For commercial vehicles, this inspection requires a significant amount of time. International border clearance is the process of electronically transferring data between a commercial vehicle and the border checkpoint so that the vehicle can pass the checkpoint with minimal or no delay. The efficiency of border crossings would be substantially improved if the vehicle could be pre-cleared to cross and only verified at the border.

International border clearance could be implemented using beacon technology since it allows the agency collecting and analyzing data to easily and quickly transfer data to and from a specific vehicle moving through the communications zone of the checkpoint specific locations at a moderate rate of speed. In-vehicle signing can be used to advise the driver to either bypass or park for inspection at the border checkpoint.

2.3 Electronic Clearance

Currently, commercial vehicles are also required to stop at state checkpoints where they undergo routine weight, credential, and safety checks. For lengthy trips, a vehicle may be required to stop and undergo similar checks a number of times. The top priority of the CVO user service is for commercial vehicles to be able to travel the nation's highways without having to make these stops.

Electronic clearance is the process of electronically transferring data between a commercial vehicle and the roadside checkpoint so that the vehicle can pass the state checkpoint without stopping. Domestic electronic clearance will allow commercial vehicles operating with either interstate or intrastate registration to pass state checkpoints at main line speed without stopping.

Electronic clearance will be implemented using beacon technology since it allows the agency that is collecting and analyzing data to easily and quickly transfer that data to and from a specific vehicle moving through the communications zone of the checkpoint at a high rate of speed. As with International Border Clearance, in-vehicle signing can be used to advise the driver how to proceed. If the vehicle is given the pull-in message, it may be only weighed and allowed to proceed or it may be given a safety inspection (Section 2.4).

2.4 Safety Inspection

A safety inspection is a check of the safety characteristics of a commercial vehicle while it has been pulled off the highway at a fixed or mobile inspection site. The inspecting agency wants the inspection to be thorough and fast so that the agency can check as many vehicles as possible that are likely to have safety violations. Beacon technology will be used to speed the inspection process because it does not require a physical connection to the vehicle, and it can transfer registration data, previous inspection data, and on-board sensor data at high transfer rates. Other equipment will also be used to measure the condition of the inspected vehicle.

Data will also be uploaded to the vehicle after the inspection, and in-vehicle signing technology may be used to instruct the driver to proceed or to notify the driver that the vehicle is to be considered out of service.

2.5 Fleet Management

A DSRC fleet management application allows fleet or individual operators to extract or upload data to and from commercial vehicles to support fleet management functions. This function will be performed through the common interface used for electronic clearance and safety inspections. Beacon readers can be placed at many locations, including terminals, warehouses, fueling facilities, commercial scales, and truck stops.

2.6 Automatic Equipment Identification (AEI) and Freight Management

AEI enables intermodal freight management to accommodate the need to track freight as it transitions from one mode of transportation to another. All tracking is expected to use AEI beacon technology (See Appendix B). Most transponders would be simple read-only tags attached to containers, but more complex electronic lock tags would also be required to indicate whether tampering had occurred with the container in border-crossing operations. The same AEI link would also be used to track individual containers in storage locations, as in freight yards and warehouses, for non-transportation-related location fixing.

2.7 Off-Line Verification

Off-line verification is a check of the data in a tag's memory when a vehicle has been stopped for any reason by an enforcement agency. Beacon technology will be used to provide a fast, common interface for data. Power unit and electronic lock tags can transmit data to a hand-held reader carried by an enforcement agent. This application will reduce the time required to obtain the data needed by the enforcement agency and will allow the commercial vehicle to quickly return to the road and the enforcement agent to return to other enforcement activities. This application can also be used by commercial operations to verify the proper operation and data content of the tag before it leaves a commercial facility.

2.8 Electronic License Plate (ELP)

The ELP application allows an enforcement agency to check the license plate number, state and expiration date, contained in a tag's memory when the tag is built into a standard size license plate. This application will reduce the time required to obtain queries on vehicles about to be stopped and allow traffic to be screened for stolen or unlicensed vehicles. Furthermore, traffic can also be screened for vehicles suspected of involvement in criminal activity. However, the largest impact of implementing the ELP is that all vehicles in a state will have a common RF interface device to the outside world and encourage commercial applications, such as Parking Payment and Drive-Thru Payment, that are dependent on common vehicle interfaces. This application will employ mobile, stationary, and portable readers.

2.9 Traffic Network Performance Monitoring

In traffic network performance monitoring, traffic management centers (TMC) monitor traffic flow parameters, such as density and speed, to detect incidents and other traffic-slowing conditions. Where high densities of vehicles that have tags for in-vehicle signing and other functions are being used, beacon technology allows the TMC to communicate with these vehicles for probe information. This enables the TMC to obtain a higher-density probe vehicle population and therefore more accurate information. The increased accuracy allows the TMC to improve its capability to determine the occurrence and location of incidents and congestion.

2.10 Traffic Information Dissemination

Traffic information dissemination is a form of in-vehicle signing that is used to warn drivers of congested traffic situations or incidents. Beacon technology provides communications to vehicles that have tags for in-vehicle signing information or other functions but may not subscribe to an ISP for route guidance. The transmitted message may alert drivers to tune to the Highway Advisory Radio (HAR) channel for more information. This application allows important traffic information to reach more vehicles more rapidly than is otherwise possible, therefore allowing more drivers to take action to avoid congestion.

2.11 Intersection Collision Avoidance

Intersection collision avoidance is a system that tracks the position and speed of vehicles within a defined area around an intersection and alerts vehicles when they are on a collision path. Sensors in the intersection will track the vehicles, processors with associated algorithms will compute the trajectories, and a beacon communications system will communicate with the vehicles. This application will provide drivers with the information necessary to take evasive action to avoid collisions.

2.12 Emergency Vehicle Signal Preemption

Emergency vehicle signal priority preemption uses beacon technology in both an intersection and an emergency vehicle to change the timing of a traffic signal and allow the emergency vehicle to proceed through the intersection with a green light and a minimum of delay. This application also reduces the probability of an accident between the emergency vehicle and affected traffic because drivers in the emergency vehicle's path respond to a control device that they are already monitoring instead of trying to determine the location and direction of the approaching emergency vehicle and formulate an independent response.

2.13 Transit Vehicle Signal Priority

Transit vehicle signal priority uses beacon technology in both an intersection and a transit vehicle to change the timing of a traffic signal and allow the vehicle to proceed through the traffic signal with a minimum of delay. This application allows the vehicle to travel its route more efficiently, deliver passengers to their destinations as quickly as possible, and consume less fuel.

2.14 Transit Vehicle Data Transfer

Transit vehicle data transfer is the uplink of operational data from and the downlink of messages to an individual transit vehicle or a fleet of transit vehicles, using beacon technology. Beacons are positioned at transit vehicle stops along a route, and communications are initiated with tag-equipped vehicles at the stops as necessary. This application allows the transit authority to conduct fare transactions with passengers in a lower cost communications structure than is possible using wide-area wireless. The transit authority also can accurately monitor vehicle ridership, track the location and on-time status of vehicles, monitor vehicle fault indicators, provide route and operational instructions to drivers, and post accurate vehicle arrival times.

2.15 Automated Highway System-to-Vehicle Communications

Automated highway system (AHS)-to-vehicle communications allow the check-in and check-out stations of the AHS to determine the status of vehicles by using on-board sensors and to present a message to enter or exit the AHS. This application uses beacon technology so that the check stations can identify the exact location of the vehicle being checked and transfer information at a high data rate.

2.16 Electronic Toll Collection

In electronic toll collection (ETC), data is transferred from and to the vehicle's tag, while the vehicle is in a toll area, and the toll fee is automatically deducted from the driver's toll account or other monetary account. Beacon technology is used so that the toll collection agency can positively identify the location of the vehicle both at the time of the toll transaction and when the vehicle enters the toll road, ensuring that the driver is billed correctly. This application allows the toll agency to reduce the cost of toll collection and allows the driver to proceed through the toll area without slowing, stopping, or experiencing traffic backups.

2.17 Parking Payments and Access Control

Using the parking payments application, a vehicle enters and exits a parking area, and the parking fee is automatically deducted from the driver's parking account or other monetary account. Beacon technology is used so that the parking agency can positively identify the location of the vehicle both at the time of the payment transaction and when the vehicle enters the parking area, ensuring that the driver is correctly billed. This application allows the parking agency to reduce the cost of parking payment collection and allows the driver to enter and leave the parking area faster. Beacon technology can also be used to transmit a message to the vehicle to proceed or that entry is not allowed into private areas, such as shipping yards, warehouses, airports, and other access restricted areas. The message is displayed in the vehicle via in-vehicle signing.

2.18 Drive-Thru Payments

Payment for products received at a drive-up service window (for example, a fast food business) could use a DSRC system to make payment more convenient. Price data could be transferred to the vehicle's tag and payment data transferred to the beacon while the vehicle is in the service area. The fee could be automatically deducted from the driver's selected monetary account. This method of payment would make the collection of money faster and therefore speed the service to the customer.

3.0 DSRC IMPLEMENTATION REQUIREMENTS

3.1 DSRC Installation Density Concerns

With many DSRC applications to implement, it is important that proper mitigation techniques be employed to prevent interference among or between applications. Methods for preventing interference include:

- Synchronizing transmissions;
- Synchronizing time division multiple access (TDMA) time slots;
- Maintaining specified separation between antennas;
- Changing power levels to reduce signal levels at the potential interference points;
- Operating at different frequencies; and
- Alternating channels.

The tag emits a signal at a very low level, and any local reader that is transmitting data overpowers the tag signals that other readers on the channel are trying to receive. Therefore, synchronizing transmissions, synchronizing TDMA time slots, and alternating channels are the methods most used to prevent interference between equipment in close proximity. However, when a channel cannot be synchronized, the transmitters must be moved apart. The distances required between independent, non-synchronized channels to prevent interference for both the same and adjacent channels can be calculated if the power outputs; antenna gains, pointing angles and beam pattern; receiver sensitivities; and separation distances are known. If synchronization of readers cannot be ensured, tag-on-tag conflict will occur if the tags are on the same channel and separated by less than some calculable distance. See Appendix D for sample calculations of reuse (separation) distances. Using a separate channel for each reader to communicate with these tags will reduce the required separation distance. The same situation applies to readers. Where synchronization of readers cannot be ensured, a reader-on-reader conflict will occur if the readers are on the same channel and separated by less than some calculable distance. A separate channel should allow operation with smaller separation distance.

For the mitigation analyses in this paper, the following assumptions are used:

- All beacons operate on a group of channels in the same frequency band (with one exception - the AEI tag);
- A vehicle may have more than one tag but only one tag is used to communicate with the various types of beacons at a time;
- The tags generally use a passive or semi-passive technology such as backscatter or modulated reflectance;
- The downlink (beacon to tag) uses binary Amplitude Modulation;
- The uplink (tag to beacon) is generated by modulating a subcarrier or subcarriers which then AM modulate the carrier signal being reflected; and
- The required bandwidth for a beacon is 3 - 6 MHz with an instantaneous data rate between 250 and 600 kbps.

The assumptions above are derived from the desire to develop a flexible DSRC system where the frequency is determined by the roadside beacon and the in-vehicle tags are designed to be as inexpensive as possible. These assumptions are also in line with the user requirements [4,5], and the design of many of the 902-928 MHz and 5.8 GHz DSRC systems investigated during this project. See Appendix A.

3.2 Mitigating Effects of Interference Between DSRC Systems

The widespread use of DSRC systems leads to the obvious problem of interference between individual beacon systems. The problem is especially difficult if all the beacons operate in the same frequency band and a single tag is capable of exchanging data with all beacons.

The analysis of interference mitigation will be developed in two parts. First, the problems and mitigation techniques for interference between two DSRC systems operating at the same frequency will be discussed. Next, a similar analysis will be presented for two DSRC systems operating at different specific frequencies within the same band.

3.2.1 Same Frequency DSRC Interference Mitigation

The assumptions on the operation of the DSRC systems listed above are used in this section to assess the problems and mitigation techniques associated with two beacons operating in close proximity at the same frequency. Examples of these scenarios include adjacent lanes in an Electronic Toll Collection (ETC) facility, or a mobile commercial vehicle tag reader operating near a wider area information beacon for in-vehicle signing. In the case of an ETC facility, careful design and integration make possible the coordination or cooperation between the beacons in the adjacent lanes. For the case of the mobile reader beacon and in-vehicle signing beacon, cooperation or coordination between the beacons is difficult to establish and unlikely to be used in practice. These two cases will be discussed separately in this section.

Assume an in-vehicle tag receives the signal from two beacons operating at the same frequency. The tag forms the envelope of the sum of the signals and attempts to detect the information being transmitted from the beacon. If the power levels of the received signals are roughly equal (~±3 dB), then the envelope of the sum of the received beacon signals will be distorted beyond recognition and no data will be transferred to the tag from either beacon. The in-vehicle tag will not respond to either beacon. Neither beacon will receive a response from the tag and the transaction or information transfer will not be completed.

If one beacon is significantly stronger than the other, then the Automatic Gain Control (AGC) and/or the AM detector will be dominated by what is received from the more powerful beacon. The data from the more powerful beacon signal will be received by the tag, and the tag will respond using the tone from the stronger beacon. The weaker beacon signal will be ignored. The stronger beacon will likewise receive the response from the tag and the transaction will be completed. Unfortunately, the beacon with the weaker signal will also receive the response from the tag which was intended for the other beacon (same frequency). The response will likely be